

# Spatial analysis of BSAI blackspotted/rougheye rockfish catch in fishery and trawl survey tows

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## Executive Summary

BSAI blackspotted/rougheye rockfish show the following attributes:

- 1) Genetic information showing spatial structure at scales < 500 km (Spencer and Rooper 2010)
- 2) High catch levels in the 1990s in the WAI that have been followed with a sharp decline in WAI survey biomass estimates beginning in 2000.
- 3) High estimated exploitation in the WAI, where they have exceeded  $U_{F40\%}$  reference exploitation rate every year from 2004-2012 except 2011.
- 4) An overall decline in survey biomass estimates in the WAI from 1991-2012, as estimated by a random effects time series model.
- 5) An increase in the proportion of survey tows which have not caught blackspotted/rougheye over all survey strata in the WAI.
- 6) A large percentage of the total harvest occurring in the WAI.
- 7) A decline in mean size in the WAI but not other BSAI subareas.

Some of the attributes above (exploitation rates, disproportionate harvesting) rely upon comparisons between catch and survey data, and it may be hypothesized that the AI trawl survey has been underestimating biomass and thus producing biased estimates of subarea biomass and exploitation rates. Analyses comparing size distributions, depths of capture, and spatial locations between fishery and survey tows do not suggest that the survey and fishery are sampling substantially different portions of the WAI blackspotted/rougheye rockfish population. The length distributions in the fishery and survey are similar to each other, with each shifting to small sizes in recent years in the WAI. A more parsimonious interpretation is that high catch levels in the WAI in the 1990s have resulted in a sharp drop in abundance beginning with the 2000 survey, continued relatively high exploitation rates have prevented the WAI population from increasing, and fish from neighboring areas have not “replenished” the fish in the WAI. The observation of decreased mean size and increased proportion of survey tows with no catch are also consistent with a population that has declined due to high exploitation rates.

The purpose of identifying stock structure is to assess the risk of population depletion if management units were larger than the biological scale of “stocks” as a result of disproportionate harvesting within the management unit. For BSAI blackspotted/rougheye rockfish, the best available evidence has shown genetic estimates of stock structure as spatial scales smaller than our management units, and disproportionate catches (and high exploitation rates) in the WAI. The WAI population has responded by showing a decrease in estimated survey abundance, increases in the proportion of survey tows with no catch, and decreases in mean size. The BSAI blackspotted/rougheye rockfish serve as an important case study illustrating the importance of recognizing stock structure in our management practices.

## Introduction

Stock structure and estimated area-specific exploitation rates have received attention from the BSAI Groundfish Plan Team in recent years, and an appendix to the 2012 BSAI blackspotted-rougheye stock assessment (Spencer and Rooper, 2012) documented high exploitation rates in the western Aleutian Islands. An initial spatial analysis of fishery and survey catch data was also presented in Spencer and Rooper (2012), and indicated that fishery catches in the western Aleutian Islands (WAI) are occurring in areas with relatively small survey abundance. The purpose of this report is to present additional analyses of fishery and survey data that pertain to the relative abundance of WAI blackspotted/rougheye rockfish that were not presented in Spencer and Rooper (2012).

This document is organized into six sections. First, the area-specific exploitation rates are updated. Second, a smoothing population model is fit to the time series of WAI survey biomass estimates. Third, time series of the proportion of tows with positive catches of blackspotted/rougheye rockfish are presented. Fourth, time series of mean size of blackspotted/rougheye obtained from the trawl survey are presented. Fifth, several analyses comparing survey and fishery catch data are presented, including length compositions, mean depth of capture, and spatial distributions of catch data. Finally, the spatial variation of target fisheries which capture blackspotted/rougheye are examined. These analyses are applied to each of four subareas in the Aleutian Islands: the WAI, the central Aleutian Islands (CAI), the eastern Aleutian Islands (EAI), and the southern Bering Sea (SBS). The location of these subareas is shown in Figure 1.

## Area-specific exploitation rates

Area-specific exploitation rates are defined here as the yearly catch within a subarea divided by an estimate of the subarea biomass at the beginning of the year. Area-specific exploitation rates are generated to assess whether subarea harvest is disproportionate to biomass, which could result in reductions of subarea biomass for stocks with spatial structure.

For each year from 2004 through 2012, the subarea biomass was obtained by partitioning the estimated total biomass (ages 3+) at the beginning of the year (obtained from 2012 BSAI blackspotted/rougheye stock assessment) into the Aleutian Islands subareas. The biomass estimates from the 2012 stock assessments are assumed to be the best available information on the time series of total biomass, and this method can be considered a “retrospective” look at past exploitation rates. For each year, a weighted average of the subarea biomass from the three most recent surveys Aleutian Islands and eastern Bering Sea slope trawl survey (weights of 4, 6, and 9, with more recent surveys receiving higher weights) was computed, and the proportions from these averages were used to partition the biomass into subareas. Catches were obtained from the Catch Accounting System database. To evaluate the potential impact upon the population, exploitation rates were compared to two measures of stock productivity: 1) 0.75 times the estimate rate of natural mortality ( $M$ ), which is the fishing mortality that produces the allowable catch,  $F_{abc}$ , for Tier 5 stocks; and 2) the exploitation rate for each year that would result from applying a fishing rate of  $F_{40\%}$  to the estimated beginning-year numbers, and this rate is defined as  $U_{F40\%}$ . The  $U_{F40\%}$  rate takes into account maturity, fishing selectivity, size at age, and time-varying number at age, and thus may be seen as more appropriate for Tier 5 stocks because harvest recommendations are based upon this age-structured information. BSAI

blackspotted/rougheye rockfish were managed as a Tier 5 stock prior to 2009, and as a Tier 3 stock since 2009.

Exploitation rates for the WAI blackspotted/rougheye have been at or above  $0.75M$  for each year from 2004-2010, and have exceeded  $U_{F40\%}$  in all years from 2004 -2012 except 2011 (Figure 2a). The values of  $U_{F40\%}$  are similar to  $0.75 * M$ , and have decreased slightly since 2004 because a large portion of the catch weight is derived from relatively young fish where the fishery selectivity (and thus fishing mortality) is relatively low. The 2011 WAI catch of 46 t is the lowest since 2007, lowering the ratio of exploitation rate/  $U_{F40\%}$  ratio to 0.78. However, the 2012 catch in the WAI has increased to 65 t. The estimate of WAI catch in 2013 (though July 27, 2013) is 61 t, and the estimated proportion of the stock in the WAI for 2013 is reduced because it incorporates the low abundance of the 2010 and 2012 surveys. Thus, the preliminary WAI exploitation rate for 2013 is increased to 1.59 times  $U_{F40\%}$ . The exploitation rates for the other subareas do not exceed  $U_{F40\%}$  with the exception of the EBS in 2010 and 2011. The high exploitation rates in the WAI reflects that a large portion of the harvest occurs in this area, relative to a small portion of the survey biomass. From 2004-2012, 43% of the harvest in the AI management area occurred in the WAI but only 8% of the survey abundance for the AI management area.

Catches in WAI from 2004-2012 appear to be decreasing, with the two highest catches occurring in 2004 and 2006 (Figure 2b). This could potentially be explained by a combination of the fishery improving their avoidance of blackspotted/rougheye rockfish bycatch, and also a potential reduction in population size.

Exploitation rates from 2004-2012 are reported here in order to focus on the recent history, but it is also worth noting that high exploitation rates have occurred in previous years. Catches by AI subarea can be calculated back to 1994, when the Blend catch database began reporting this subarea AI catches. In 5 of the 6 years between 1996 and 2001 the estimated WAI catch of blackspotted/rougheye exceeded 100 tons, including estimated catches of 446t and 513t in 1996 and 1997, respectively, that are at least 3.5 times larger than the catch for any other year in the WAI since 1994. Given these large catches in the late 1990s, it is not unexpected that the population has shown a decline, as shown in Figure 2c and discussed further in the following section.

### **Trends in population abundance**

A key element of the estimated exploitation rates of WAI blackspotted/rougheye is whether the decline in survey abundance represents a true decline or is simply the realization of a randomly varying time series high interannual variation but no trend. The coefficients of variation (CV) of the point estimates of survey biomass are relatively high, averaging 0.44 from 1991-2012, but the point estimates are decline consistently. The average biomass from the 1991-1997 surveys was 3,156 t and the average from the 2000-2010 surveys was 1,059 t. In the 2012 survey, the biomass estimate was further reduced to 355 t. A relatively sharp decline has appears to have occurred between the 1997 and 2000 surveys, consistent with the high catches in the late 1990s mentioned above.

Simple population models that “smooth” time series of survey biomass estimates can be used help distinguish between “process” errors (i.e., the variation of the true population) from “observation” errors (i.e., the variation associated with estimates of the true population). A simple model for smoothing time series of survey data being considered by the North Pacific Fisheries Management Council Groundfish Plan Teams is a random walk random effects model.

In this model, the estimated CVs of the survey biomass point estimates are used as the observation error variance, and the process error variance is estimated by the model. Cases where the estimated survey CVs are very large relative to the variability in the point estimates would result in the inability to estimate the process error variance, yielding a constant level of the “true” survey biomass with no trend over time. In contrast, application of the random walk smoothing model to cases in which the underlying population trend is not swamped with observation error should yield estimates of the any temporal pattern in the true abundance.

The fits of the random effects model to the survey biomass estimates to each of the four AI subareas show substantial variability, resulting from the spatial variation in the trends in survey biomass estimates (Figure 3). The estimated initial and most recent biomass estimates, corresponding to years 1991 and 2012, are denoted  $S_{1991}$  and  $S_{2012}$ , respectively, and are shown below. In the WAI, the ratio of recent to initial biomass estimates was 15%. The EAI is an example where the observation error has swamped any underlying process variability, resulting in an estimated flat survey trajectory. The overall trajectory has been relatively flat in the CAI, whereas an estimated decline in the SBS can be attributed to only the most recent two surveys. Finally, the 1991 survey biomass estimate is not a measure of unfished stock size, as harvesting has occurred prior to 1991. Thus, the more common status indicator of stock size relative to the unfished stock size would be expected to show a more precipitous decline in the WAI than observed with the post-1991 survey data.

	WAI	CAI	EAI	SBS
$S_{1991}$	2971 t	2925 t	3951 t	687 t
$S_{2012}$	455 t	3934 t	3951 t	371 t
$S_{2012}/S_{1991}$	0.15	1.34	1.00	0.54

### Proportion of tows with no catch

Marine populations are often highly aggregated, which results in highly skewed frequency distributions that pose difficulties in obtaining abundance estimates of reasonable precision (Pennington 1983). One approach for aggregated population is to conduct presence-absence sampling, in which the proportion of sampling units in which the species occurs is recorded. Presence-absence data is useful in studies of species distributions and defining habitat, but can also be used to estimate abundance (Mangel and Smith 1990, Zhou and Griffiths 2007). For example, Mangel and Smith (1990) show an example for a highly aggregated population in which the abundance estimate based on presence-absence sampling had lower variability than estimates based on count data. For these reasons, it is useful to examine the proportion of tows in which blackspotted/rougheye rockfish have been observed in the trawl survey, as this index is not affected by the random effect of sampling one or two large tows which can substantially affect the sample mean.

Excluding survey strata < 100 m (where blackspotted/rougheye rockfish are not found) leaves six survey strata in the WAI, corresponding to three depth zones (100-200m, 200-300m, and 300-500m) on either side of 175°E. Over the six strata, the proportion of survey tows that did not catch blackspotted/rougheye rockfish increased from 60% in 1991 to 89% in 2012 (Figure 4). The proportion of survey tows in the WAI with no catch has steadily increased throughout the 1991-2012 period, although a sharp increase occurred from 1994 (65%) to 2000 (80%), roughly corresponding to the period of high catches.

Aggregated over all strata, the increased proportion in the number of tows with no catch could have resulted from changes in strata with relatively low densities. However, the increase in

the proportion of tows with no catch was observed in each of the six strata. Figure 5 summarizes, by strata, the temporal changes in mean CPUE and the proportion of tows with no catch, with the beginning and end periods representing the 1991-1994 and 2010-2012 survey, respectively. The proportion of tows with no catch increased in all strata, including the strata with the highest densities (which were east of 175°E).

### **Changes in mean size**

Stocks that are declining in abundance due to fishing pressure would generally be expected to show reduced size and age, as the increased mortality reduces the number of fish that live long enough to achieve large sizes. The AI survey length composition indicates that the proportion of the WAI population at relatively small sizes has increased since the early 1990s (Figure 6). For example, the proportion of the survey length composition less than 30 cm has ranged between 0 – 10% from 1991-1997, from 1 – 25% from 2000 -2004, and from 45 – 52% from 2006 – 2012. In contrast, the relative survey length compositions in the CAI and EAI appear to have changed little since 1991 (Figure 6).

An ANOVA was used to test for significant differences in the mean size between areas. For each survey haul where blackspotted/rougeye rockfish were captured, mean length for the haul was weighted by the relative contribution of the haul (indicted by numerical CPUE) to the estimated population size for the stratum in which the haul occurred.

A plot of mean size by area from 1991- 2012 is shown in Figure 7. The mean sizes within the CAI, and EAI are similar to each other and show roughly the same trend over time, which is a slight increase in mean size from 1991 – 2000, and with relatively constant (CAI) or slightly lower values (EAI) since 2000. The mean size in the SBS is relatively constant throughout the time series. The mean size in the WAI increased from 1991 – 2002, showing a similar pattern to that in the CAI and EAI. However, the mean size has declined from 45 cm in 2002 to 32 cm in 2012.

The full ANOVA indicated significant ( $P < 0.05$ ) effects for year, area, and the year\*area interaction, which was largely driven by the different pattern by year in the WAI. Simpler ANOVA models were applied to each of the four areas to test for a year effect within each area. The year effect was non-significant in the SBS ( $P > 0.24$ ). In the CAI the year effect was significant ( $P < 0.05$ ) but pairwise testing of differences between years using Tukey's HSD procedure yielded no significant comparisons. This result stems from the ANOVA procedure testing for a general effect of year on size whereas Tukey's HSD is a more conservative test that accounts for all multiple comparisons. Significant differences between years were observed in the EAI; for example, the mean size in 1991 was significantly lower than the mean size in 1997, 2000, 2004, and 2006, and the mean sizes in 2010 and 2012 were each significantly lower than the mean sizes in 2000 and 2004. However, maximum difference in mean size between any two years did not exceed 5 cm, perhaps implying that the result may be statistically significant but not biologically meaningful. In contrast, the mean sizes in 2010 and 2012 in the WAI were each significantly lower than the mean sizes in 1997 and 2002, and the differences in mean size between years commonly approached or exceeded 10 cm.

### **Comparisons of fishery and survey data**

With the exception of exploitation rates, the analyses above have been applied to only the trawl survey data without considering fishery information. It is reasonable to consider whether the observed exploration rates could be attributed to the fishery and survey sampling different

portions of the population, which could result in misleading patterns of exploitation rates, mean sizes, and trends in estimated biomass and proportion of tows with positive catch.

#### *Size distribution of blackspotted/rougheye rockfish in fishery and survey tows*

The fishery and survey length composition data are used to evaluate whether the fishery and survey are capturing different size ranges of blackspotted/rougheye. If this were the case, temporal trends could possibly occur if, for example, the survey was undersampling a portion of the size range relative to the fishery catches and the degree of undersampling has changed over time. Due to inconsistent sample sizes of length compositions in the Observer Program database, fishery and survey data were grouped into four periods: 1990-1994, 2000-2002, 2004-2006, and 2010-2012. Observations on fishery length compositions for the years within each period and area are combined and presented as cumulative distributions. The survey data are treated in a similar manner, combining the survey population estimates at length for the two surveys within each period. The length distributions of blackspotted/rougheye rockfish captured were very similar for most of the combinations of time period and area (Figure 8). For the 2004-2006 period in the WAI, the survey captured a broader range of size than the fishery, which resulted from the survey length composition having a relative large portion less than 30 cm, whereas the fishery catches during this period were primarily > 40 cm. However, by the 2010-2012 period both the survey and fishery were capturing a similar range of sizes, which was reduced from the range of sizes captured during earlier periods. The ranges of sizes captured in the CAI and EAI differed little between the fishery and survey with little temporal trends in either case, with the exception of smaller fish being captured in the fishery than the survey from 2010-2012 in the CAI.

#### *Depth of capture of blackspotted/rougheye rockfish in fishery and survey tows*

A related analysis was performed to examine the depths at which blackspotted/rougheye are captured in the fishery and the survey data. If the fishery catches consistently occur at different depths than the depths at which the survey catches occur at, it could indicate that the fishery and survey are sampling different habitats. Bottom depth and number of blackspotted/rougheye rockfish caught from fishery and survey tows were obtained, and an ANOVA was conducted in which bottom depth (weighted by number of fish caught) was modeled as a function of year, BSAI subarea, and sampling source (i.e., fishery or survey).

The weighted mean depths for the WAI, CAI, and EAI are shown in Figure 9. The fishery catches are presented as either from all gear types or from trawl gear, with the difference being primarily catches in longline gear. In most years and areas the fishery catches occur in shallower water than the survey catches, although the fishery depth of capture has been increasing since about 2002 in both the WAI and the EAI. In the WAI this results from increasing depths for tows targeting POP, whereas in the EAI this results from changes in species composition of hauls capturing blackspotted/rougheye (i.e., more blackspotted/rougheye are being captured recently in hauls in which the dominant species is arrowtooth flounder or “other” species). A summary of the results of the ANOVA analysis is shown below:

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Year	22	2.90E+09	131628191	66.747	< 2e-16
Area	3	2.54E+09	845474952	428.728	< 2e-16
F_S	1	3.60E+07	35985446	18.248	1.95E-05
Area:F_S	2	6.90E+06	3449425	1.749	0.174
Year:F_S	8	1.48E+07	1850872	0.939	0.483
Year:Area	52	2.97E+09	57052963	28.931	< 2e-16
Year:Area:F_S	16	1.51E+07	944710	0.479	0.958
Residuals	15131	2.98E+10	1972053		

The year, area, and sampling source (i.e., fishery or survey, denoted F\_S in the table above) were all significant. As noted above, differences in depth of capture occur between the fishery and survey, and differences also occur between areas and over time. Of particular interest, however, are the interaction terms: does the effect of the sampling source differ between areas? In other words, could the patterns of high estimated exploitation rates in the WAI be explained by the relationship between the fishery and survey depths of capture being different in the WAI than in other areas? This can be evaluated with the *area:F\_S* interaction, which was not significant ( $P < 0.17$ ). It is also useful to note the period for which high exploitation rates have been estimated for the WAI (2004-2012) corresponds to the fishery depths of capture in the WAI becoming deeper and more similar to the survey depths of capture. The relationship between fishery and survey depths of capture appears similar between the WAI and EAI, although the EAI does not show a pattern of estimated high exploitation rates.

#### *Spatial location of fishery and survey tows in the WAI*

The final comparison to make is the spatial location of fishery and survey tows in the WAI. Both the fishery and survey data indicate a large portion of the WAI biomass is located between 175°E and 177°E, which are the easternmost two degrees of longitude within the WAI. This is indicated in Figure 10, which shows the proportion, by year, of fishery catch and the proportion of survey CPUE (kg/km<sup>2</sup>) in 1° longitude bins within the WAI. In each survey since 2002 (with the exception of 2006), more than 80% of the summed CPUE occurred between 175°E and 177°E, and the distribution of fishery catches shows a similar pattern from 2002-2008. However, a substantial proportion of the fishery catches occur between 174°E and 175°E, with increased proportions in recent years. Between 2002-2008, the proportion of catches in this area ranged between 7% and 27%, whereas the proportion exceeded 31% in 3 of the 4 years from 2009-2012. This is an area with small values of summed survey CPUE.

The distribution of the tows by half-degree longitude bins is shown in Figure 11, and indicates that the survey essentially does not sample habitat in the half-degree longitude bin centered at 174.75° E. From 1991-1999, the fishery also had a fairly low proportion of tows in this bin (< 10%), so the distribution by longitude between the fishery and survey were relatively similar in this period. However, from 2000-2012 the proportion of fishery tows in this bin has increased to nearly 25%, and it is now the longitude bin with the most fishery effort.

The habitat near 175° indicates several locations which are not sampled by the survey but do contribute to the fishery catch. The location of fishery tows are shown in the blue ovals in Figure 12 (locations of actual fishery tows are not shown due to confidentiality constraints), and consist of an area in the northern portion of the Aleutian Islands that bisects 175° E, and two southern areas on either side of 175° E. The locations for Aleutian Island trawl survey tows is primarily drawn from location that have been successfully sampled in the past surveys, which are shown as the green grid cells in Figure 12. The locations of survey grid cells for which sampling has been attempted and the habitat was deemed untrawlable is shown by red grid cells in Figure 12. Because untrawlable cells and unsampled cells are treated nearly equivalently in the Aleutian Islands trawl survey, it is very unlikely that survey tows would be attempted in these areas in future surveys.

A key question is whether the survey sampling has been missing an important component of the population by not sampling these fishing grounds. The lack of standardized trawl survey tows in these areas poses a challenge for inferring population sizes, but some information on relative abundance can be obtained from comparing fishery catch data (from the fishery Observer database) between years and areas. The fishery data was filtered to attempt to ensure consistent fishing catchability between years, and also reduce differences between the fishery and survey data. Fishery hauls were restricted to vessels targeting POP during from late spring through summer (May- September) at depths between 200-300m, and hauls from the 5 vessels with the highest blackspotted/rougheye catch from 1998-2012 were selected for analysis. The table below shows the number of filtered hauls per year; from 1998-2012, the filtered hauls represented 44% of the total observed hauls targeting POP in the WAI area.

Year	Filtered hauls	All POP tows
1998	16	67
1999	38	104
2000	30	75
2001	21	42
2002	44	69
2003	44	98
2004	38	71
2005	23	63
2006	47	96
2007	81	119
2008	101	162
2009	59	120
2010	70	118
2011	120	172
2012	109	182
Total	842	1921

The analysis of fishery data was restricted three longitude bins in the eastern portion of the WAI: 174.5° E -175° E, 175° E -176° E, and 176° E -177° E. As noted above, fishery catches are not common west of these locations. For each of these longitude bins, fishery CPUE (kg/hour), the proportion of tows with no catch, and tons of blackspotted/rougheye caught per ton of POP for the filtered fishery tows were computed by year. The 176°E - 177°E area has shown relatively high fishery CPUE values and low proportions of tows with no catch (with the exception of 2002) (Figure 13), which is consistent with both the high fishery catches and survey CPUE data for this area. An overall decline in catch rate in the 176°E - 177°E area from 2004-2012 is also consistent with the declining catch and exploitation rates for the WAI (Figure



2). In contrast, the area between 174.5°E to 175°E, which is not sampled by the survey, is characterized by low CPUE, low bycatch rates, and high proportion of no catch prior to 2009. The area between 175°E to 176°E appeared to follow similar trends as the area between 174.5°E to 175°E.

In 2009, 2010, and 2012, the CPUE and bycatch rates began to increase in 174.5°E to 175°E area, and the proportion of catches with no catch decreased. However, it is not clear that these represent increases in biomass within this longitude bin. First, the fishing grounds covered by these vessels have been shifting within this longitude bin, which has resulted in a reduction in the mean latitude of tows (Figure 14). If the fishery tows have been shifting to areas with higher blackspotted/rougheye densities, this could explain the apparent recent changes in mean CPUE, proportion of tows with no catch, and bycatch rate. Secondly, the high CPUE values for 2009, 2010, and 2012 have come from highly skewed population distributions (Figure 15), resulting in the mean values shown in Figure 13 being strongly influenced by very small number of tows. A shift in fishing grounds could also potentially result in an increased chance of obtaining a few particularly large tows which would skew mean CPUE upwards. Finally, the total biomass of blackspotted/rougheye rockfish within the 174.5-175 longitude bin is a function of not only the density, but also habitat area, and this longitude bin has relatively small habitat area compared more eastward locations within the WAI.

It would be preferable if the Aleutian Islands trawl survey sampled the 174.5°E to 175°E longitude bin in order to more precisely assess the population density of blackspotted/rougheye rockfish (and other species) in this area. However, the three metrics of fishery catch rates examined here do not suggest that this area has high densities that would grossly affect the AI survey data and the interpretation of WAI exploitation rates. In fact, very low fishery catch rates were observed in the 174.5°E to 175°E longitude bin from 2002-2008, which corresponds to a period containing some of the highest estimated WAI exploitation rates (Figure 2). Although the 174.5°E - 175°E and 175°E - 176°E longitude bins are small relative to our spatial management units, each of these areas is large enough to contain multiple distinct fishing areas. The relative distribution of fishing effort for these filtered tows has not remained constant over time, which could account for the apparent recent increases in fishery CPUE.

### **Spatial variation in fisheries which harvest blackspotted/rougheye rockfish**

The impact of fishing effort upon catch can be considered with a simple model

$$C = qEB$$

where  $C$  is the rate of catch (i.e., tons per year),  $E$  is the rate of fishing effort,  $B$  is biomass, and  $q$  is a fishery catchability coefficient – the rate at which each unit of fishing effort removes biomass from the stock. High catches in the WAI relative to other AI subareas could thus be attributed to three factors –  $q$ ,  $E$ , or  $B$ . The WAI has a lower number of observed tows at depths > 100m than other AI subareas (Figure 16), so increased fishing effort can be ruled out. The Aleutian Island trawl survey indicates that the WAI has lower levels of biomass than other AI subareas. Although the grounds covered by the trawl survey could (and should) be improved, it seems unlikely that this would substantially affect estimates of the relative distribution of biomass among the AI subareas. However, it is plausible that the fishery catchability coefficient is not a fixed number, but varies between subareas (and likely between years as well). For a stock in which the harvest is taken as bycatch in other target fisheries, the fishery catchability coefficient reflects the degree to which fishers are able to avoid the bycatch while targeting the species of interest. The target species in which blackspotted/rougheye are captured differs

between AI subareas – in the WAI catch is obtained primarily in the POP fishery, in the CAI catch is divided between the POP, Pacific cod, and Atka mackerel fisheries, and the EAI catch is obtained in some hauls dominated by species such as arrowtooth flounder and Kamchatka flounder that do not occur further west. These patterns are shown in Figure 17, which shows the distribution of total catch from 2004-2012 across target fisheries (defined by gear type and dominant species) by subarea. Given this spatial variability in target fisheries that captured blackspotted/rougheye, it would be expected that the catchability coefficient would differ between areas.

## Summary and Conclusions

BSAI blackspotted/rougheye rockfish show the following attributes:

- 1) Genetic information showing spatial structure at scales < 500 km (Spencer and Rooper 2010)
- 2) High catch levels in the 1990s in the WAI that have been followed with a sharp decline in WAI survey biomass estimates beginning in 2000.
- 3) High estimated exploitation in the WAI, where they have exceeded  $U_{F40\%}$  reference exploitation rate every year from 2004-2012 except 2011.
- 4) An overall decline in survey biomass estimates in the WAI from 1991-2012, as estimated by a random effects time series model.
- 5) An increase in the proportion of survey tows which have not caught blackspotted/rougheye over all survey strata in the WAI.
- 6) A large percentage of the total harvest occurring in the WAI.
- 7) A decline in mean size in the WAI but not other BSAI subareas.

Some of the attributes above (exploitation rates, disproportionate harvesting) rely upon comparisons between catch and survey data, and it may be hypothesized that the AI trawl survey has been underestimating biomass and thus producing biased estimates of subarea biomass and exploitation rates. Analyses comparing size distributions, depths of capture, and spatial locations between fishery and survey tows do not suggest that the survey and fishery are sampling substantially different portions of the WAI blackspotted/rougheye rockfish population. The length distributions in the fishery and survey are similar to each other, with each shifting to small sizes in recent years in the WAI. A more parsimonious interpretation is that high catch levels in the WAI in the 1990s have resulted in a sharp drop in abundance beginning with the 2000 survey, continued relatively high exploitation rates have prevented the WAI population from increasing, and fish from neighboring areas have not “replenished” the fish in the WAI. The observation of decreased mean size and increased proportion of survey tows with no catch are also consistent with a population that has declined due to high exploitation rates.

The purpose of identifying stock structure is to assess the risk of population depletion if management units were larger than the biological scale of “stocks” as a result of disproportionate harvesting within the management unit. For BSAI blackspotted/rougheye rockfish, the best available evidence has shown genetic estimates of stock structure as spatial scales smaller than our management units, and disproportionate catches (and high exploitation rates) in the WAI. The WAI population has responded by showing a decrease in estimated survey abundance, increases in the proportion of survey tows with no catch, and decreases in mean size. The BSAI blackspotted/rougheye rockfish serve as an important case study illustrating the importance of recognizing stock structure in our management practices.

## References

- Mangel, M. and Smith, P.E. 1990. Presence-absence sampling for fisheries management. *Can J. Fish. Aquat. Sci* 47:1875-1887.
- Pennington, 1983. Efficient estimators of abundance, for fish and plankton surveys. *Biometrics* 39:281-286.
- Spencer, P.D., and C.N. Rooper. 2012. Assessment of the blackspotted and rougheye rockfish complex in the eastern Bering Sea and Aleutian Islands. In Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions, pp. 1423-1496. North Pacific Fishery Management Council, 605 W. 4th Ave, suite 306. Anchorage, AK 99501
- Spencer, P.D., and C.N. Rooper. 2010. Assessment of the blackspotted and rougheye rockfish complex in the eastern Bering Sea and Aleutian Islands. In Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands region as projected for 2011, pp. 1127-1194. North Pacific Fishery Management Council, 605 W. 4th Ave, suite 306. Anchorage, AK 99501
- Zhou, S. and Griffiths, S.P. 2007. Estimating abundance from detection-nondetection data for randomly distributed or aggregated elusive populations. *Ecography* 30:537-549.

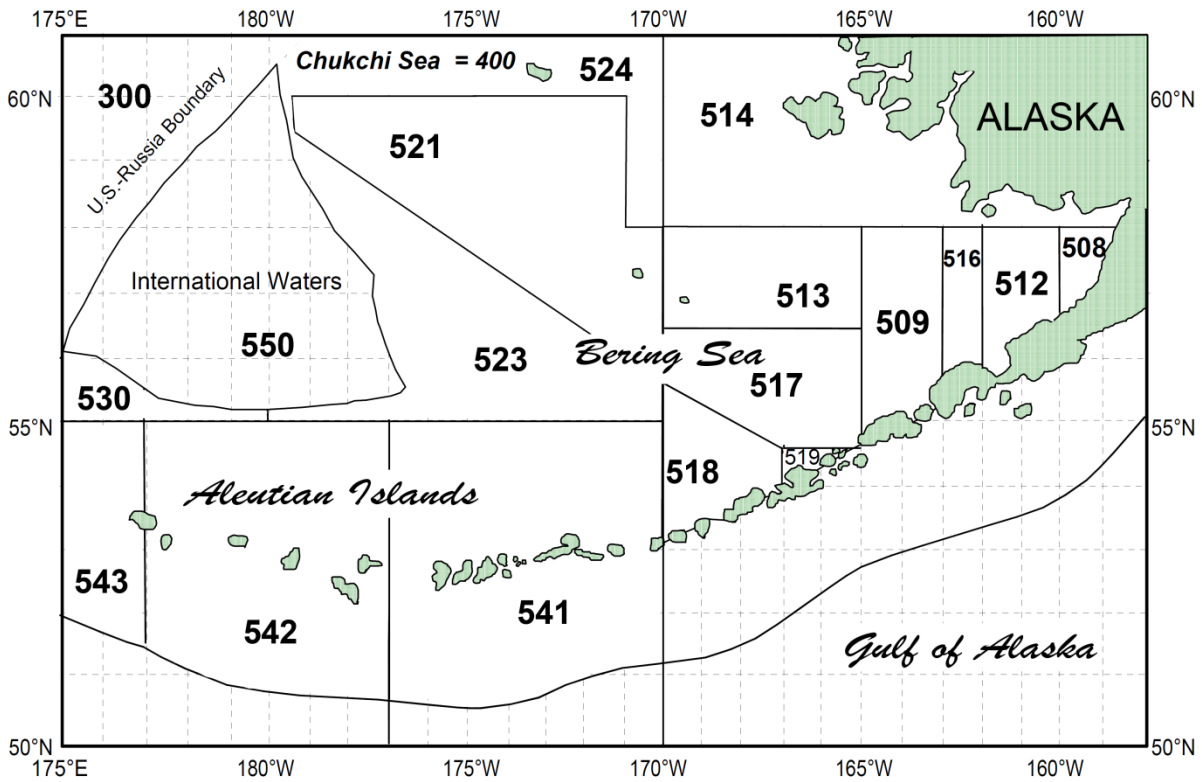


Figure 1. Map of statistical reporting zones in the BSAI management area. The western Aleutian area is zone 543 (which extends west to 170°E), the southern Bering Sea (SBS) zone comprises zones 518 and 519, and the central Aleutian Islands (CAI) and eastern Aleutian Islands (EAI) zones are 542 and 541, respectively. Figure obtained from the NOAA-Alaska Regional Management Office.

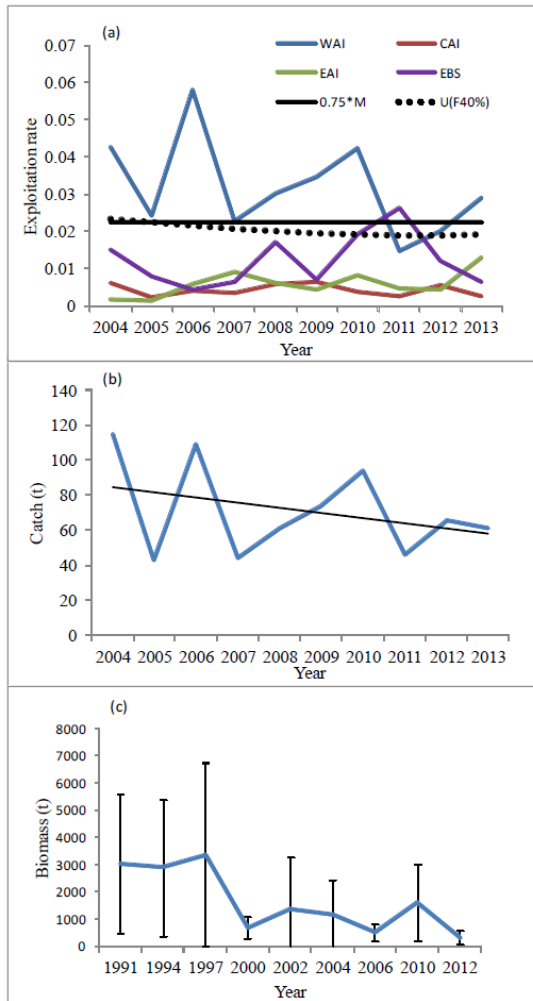


Figure 2. BSAI blackspotted/rougheye subarea exploitation rates (a), and catch (b) and trawl survey biomass estimates (c, with 95% confidence intervals) for the western Aleutian Islands. Exploitation rates and catch for 2013 are preliminary and are based on the 2012 stock projection model and catches through July 27, 2013.

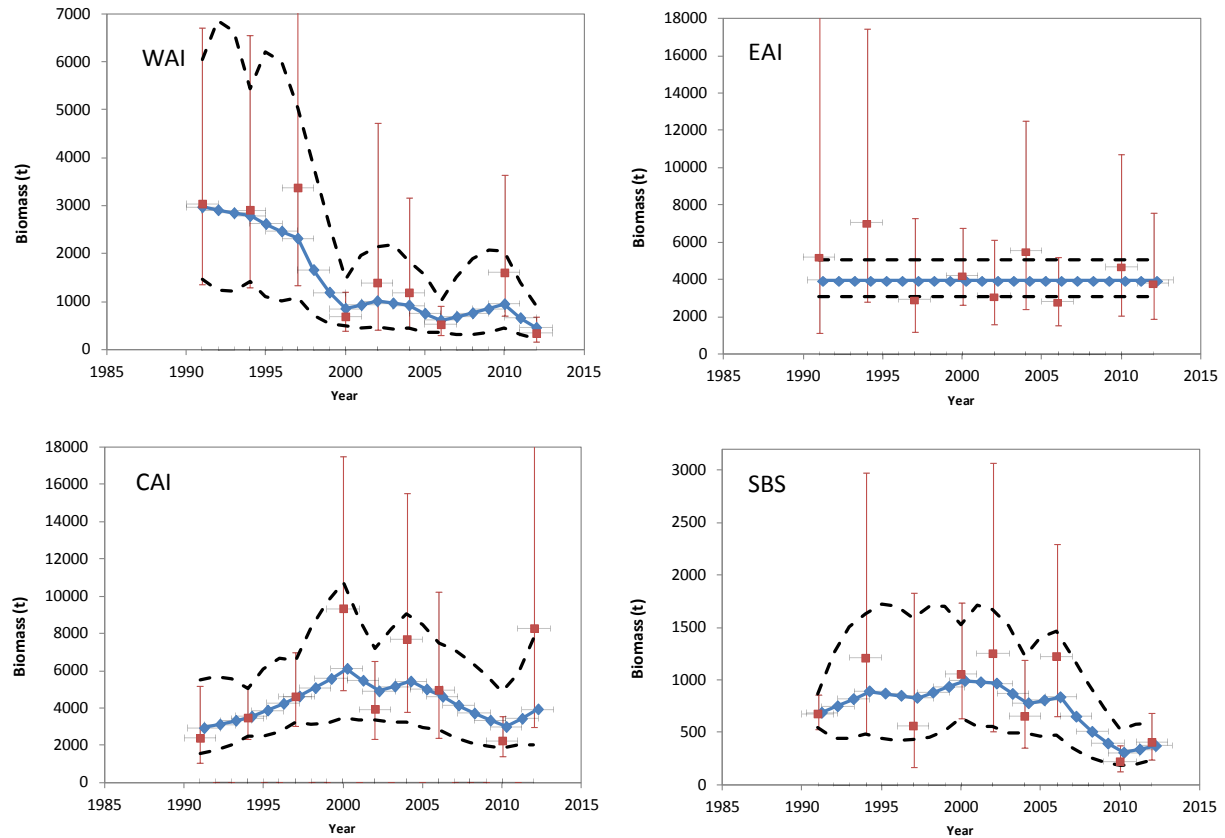


Figure 3. Survey biomass estimates of blackspotted/rougheye, and fit from a random effects random walk models, for four AI survey subareas. Error bars and dashed lines are 95% confidence intervals for the survey observations and estimated survey biomass, respectively.

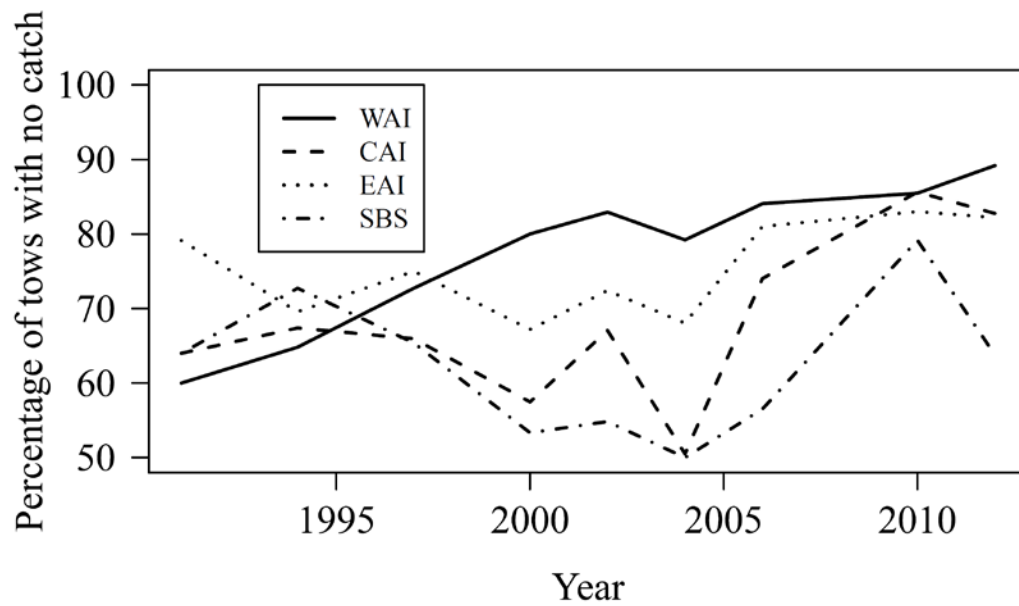


Figure 4. The percentage of AI trawl survey tows deeper than 100m in which blackspotted/rougheye rockfish were not caught, by year and AI subarea.

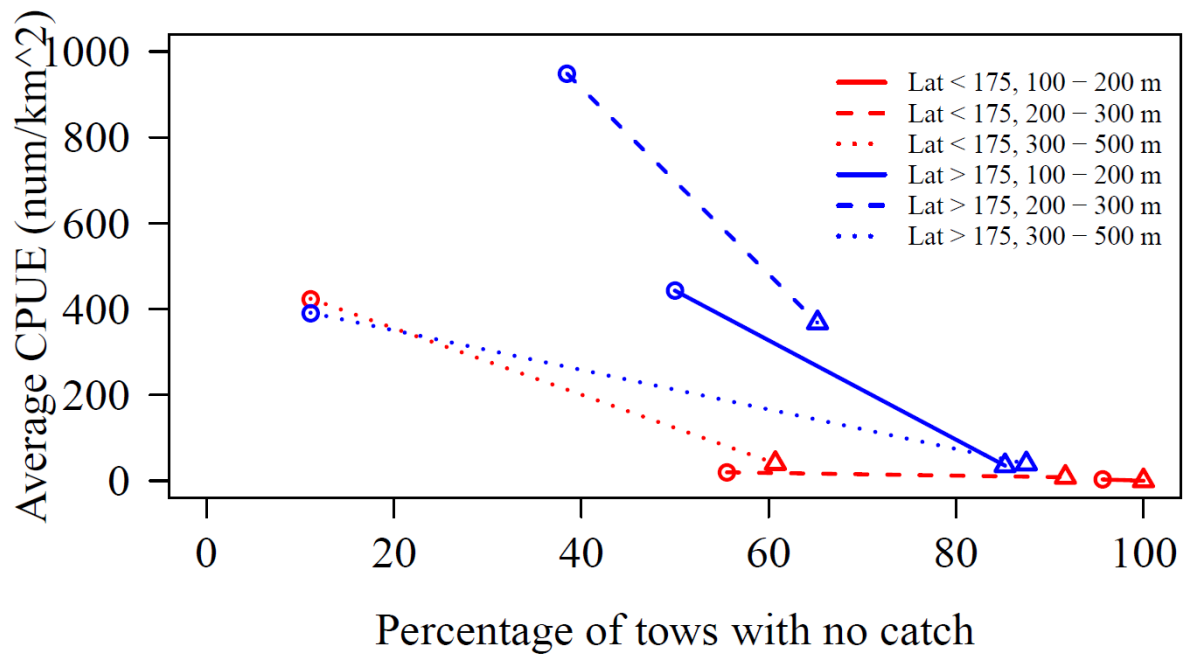


Figure 5. The change in percentage of AI survey tows with no catch of blackspotted/rougeye, and average CPUE, from 1991-1994 (circles) and 2010-2012 (triangles) for six AI survey strata in the WAI. Blue symbols/lines indicate the easternmost strata within the WAI subarea.



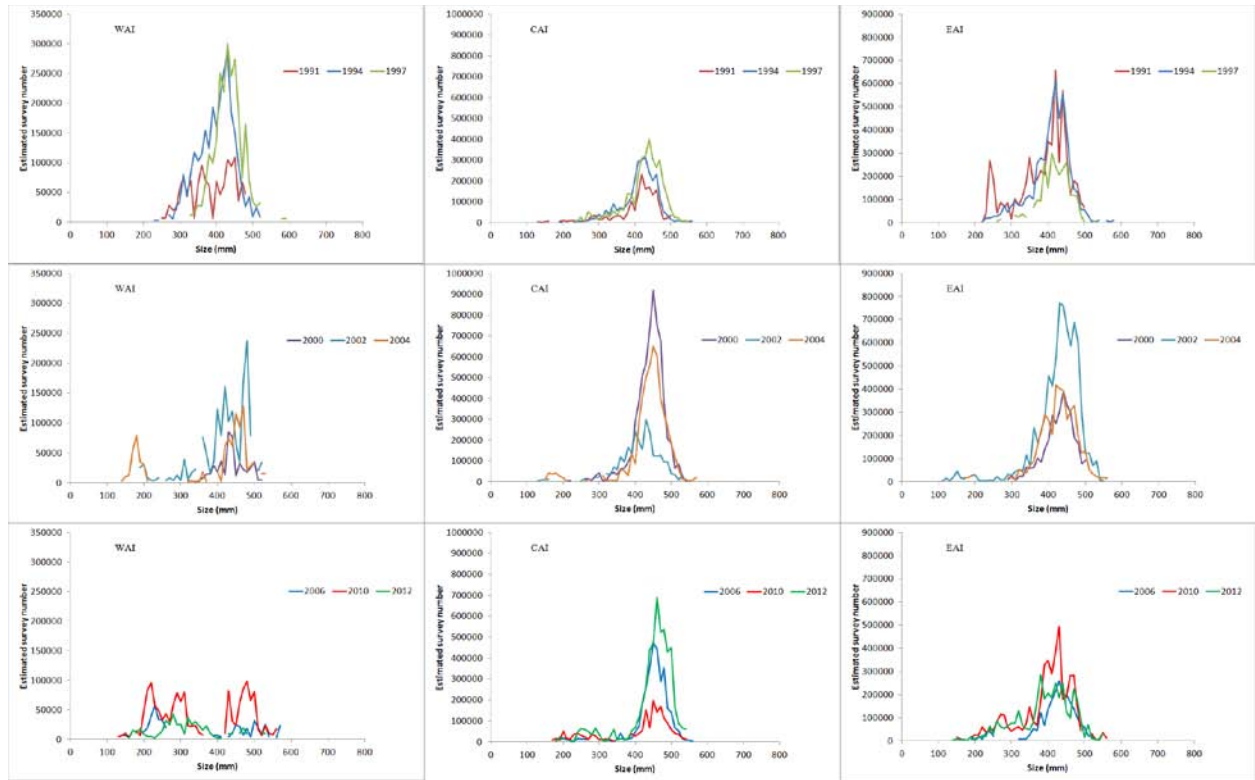


Figure 6. Blackspotted/rougheye population numbers by size estimated from the AI trawl survey, by AI subarea and survey year.

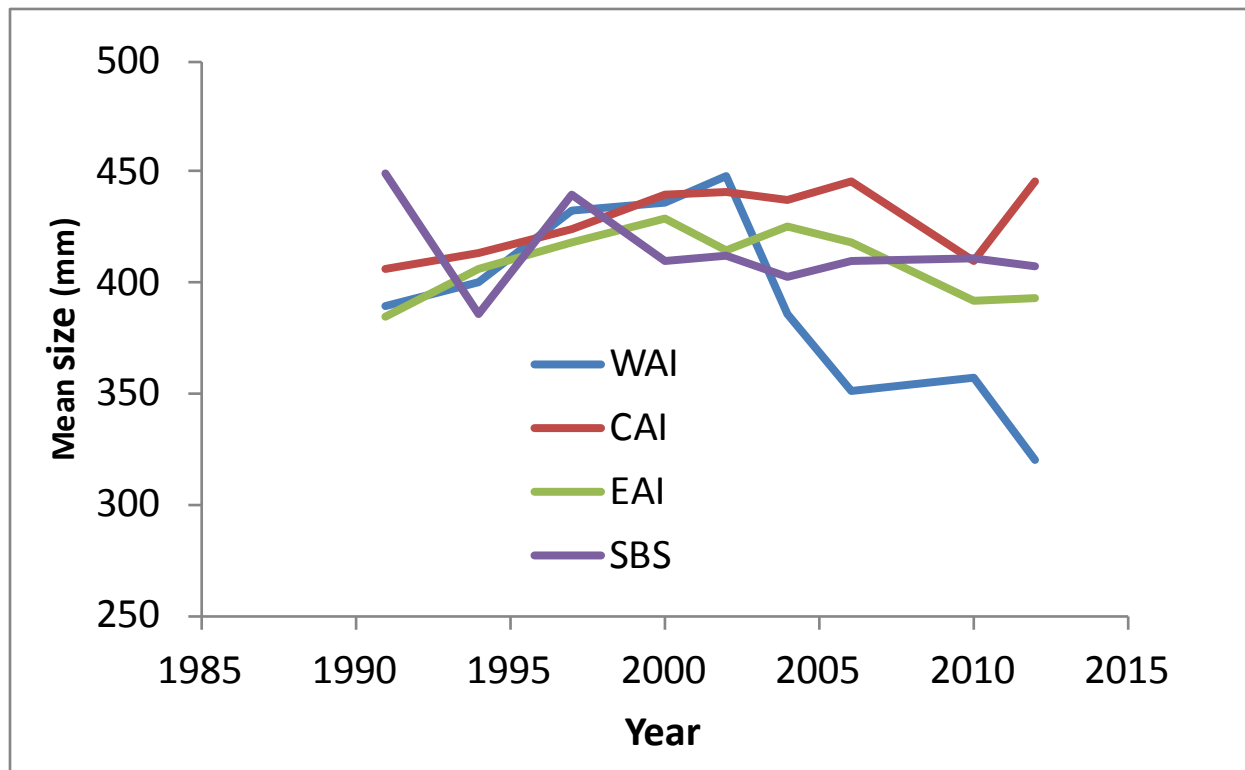


Figure 7. Mean size of blackspotted/rougheye estimated from the AI trawl survey, by AI subarea and year.

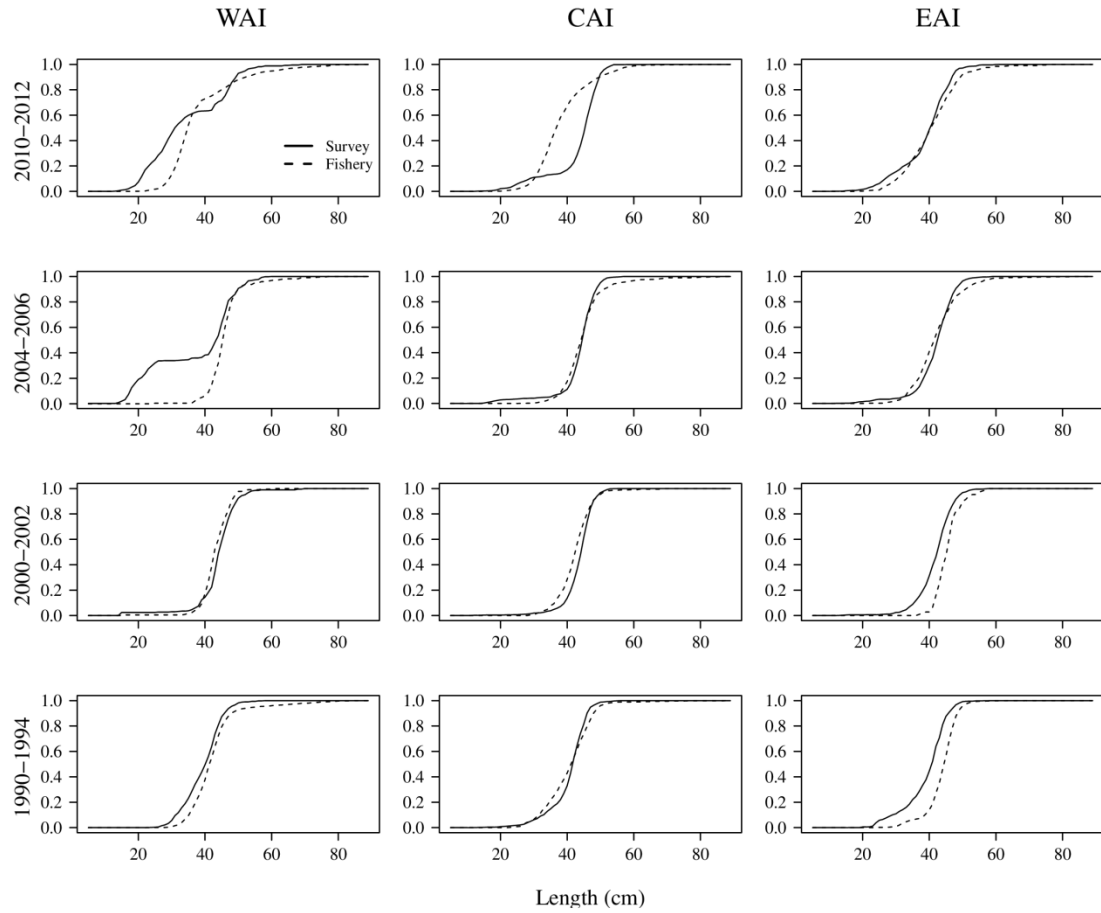


Figure 8. Length composition data from the AI trawl survey and observed fishery tows in AI subareas and four time blocks.

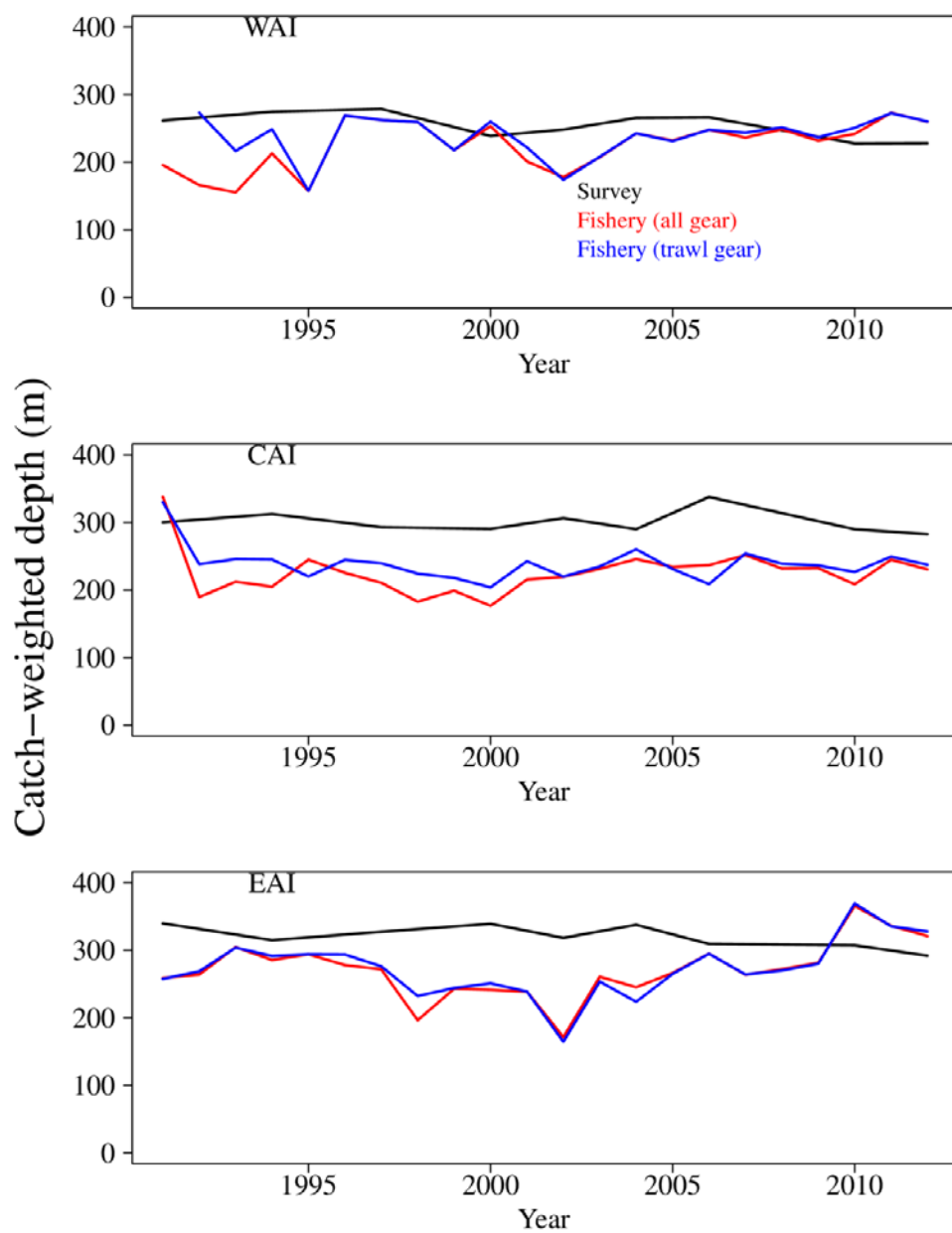


Figure 9. Catch-weighted mean depth of capture of blackspotted/rougheye rockfish for fishery and AI survey tows from 1991-2012 by AI subarea. Differences between the red and blue fishery lines represent the effect of longline gear.

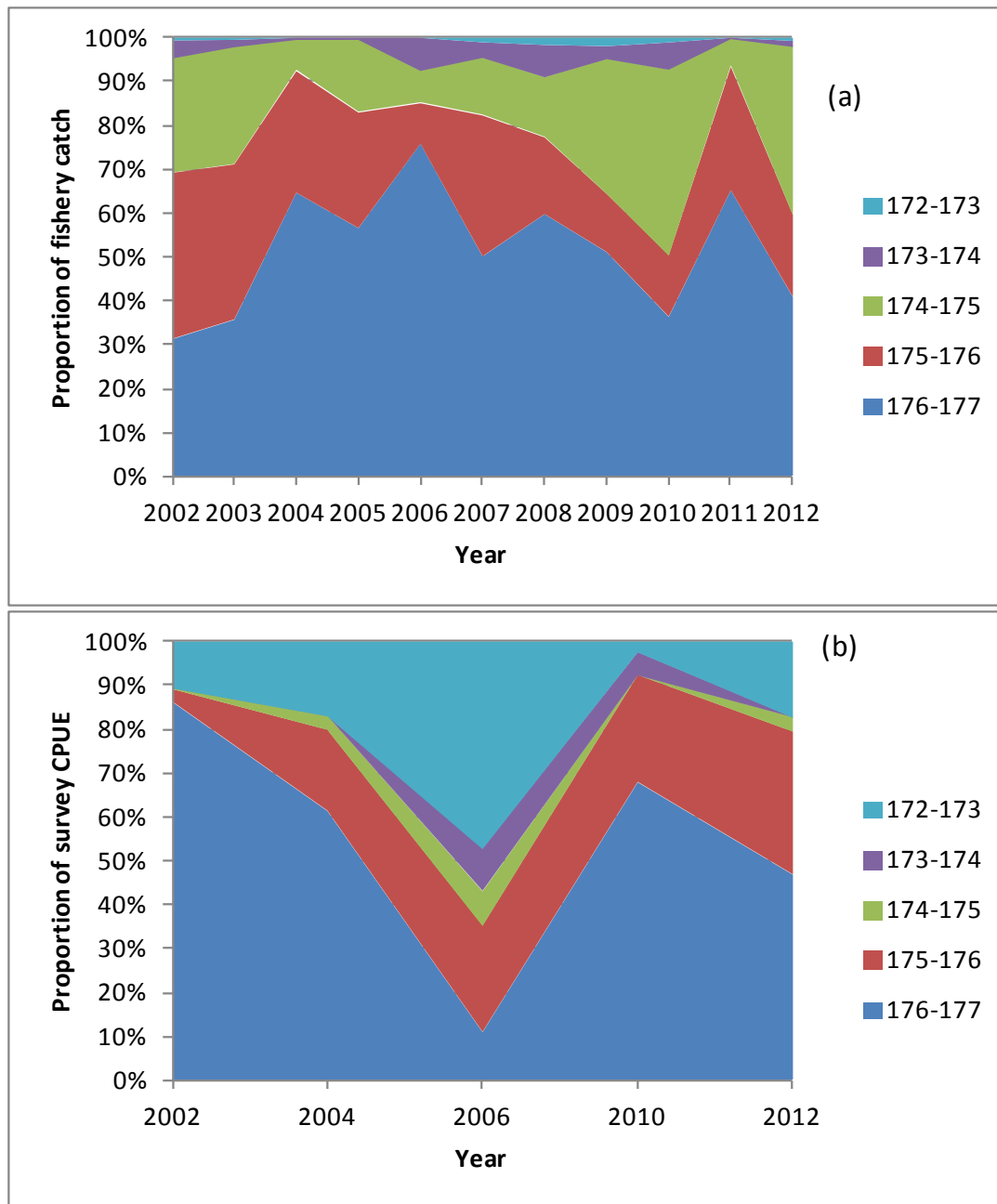


Figure 10. The proportion of fishery catch (a) and summed CPUE from AI survey tows (b) by 1° longitude bins in the WAI from 2002-2012; the easternmost bin within the WAI occurs between 176°E and 177°E.

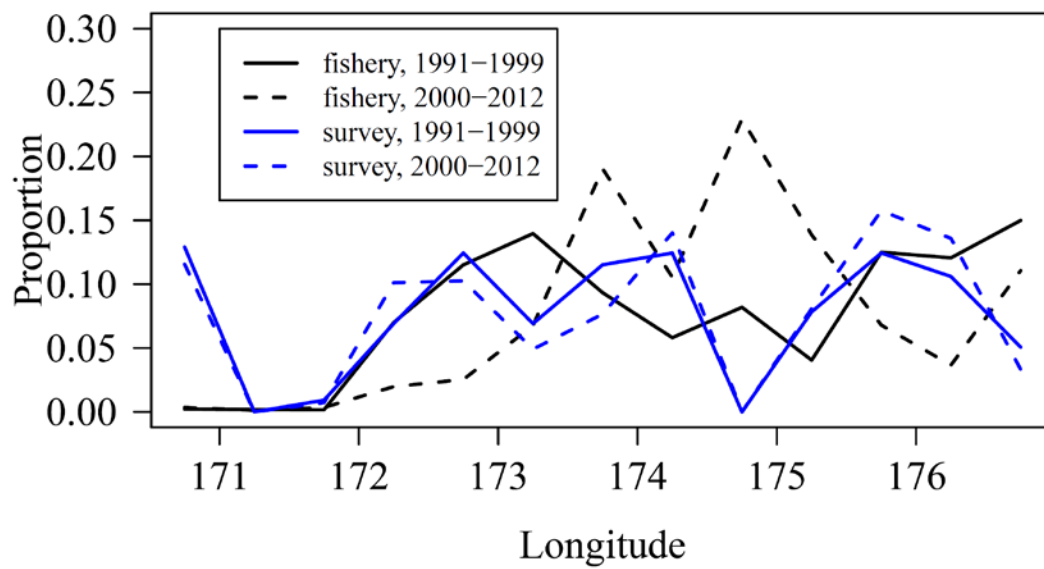


Figure 11. Proportion of survey and fishery tows within the WAI by  $\frac{1}{2}$  degree of longitude during the 1990s (solid lines) and since 2000 (dashed lines).

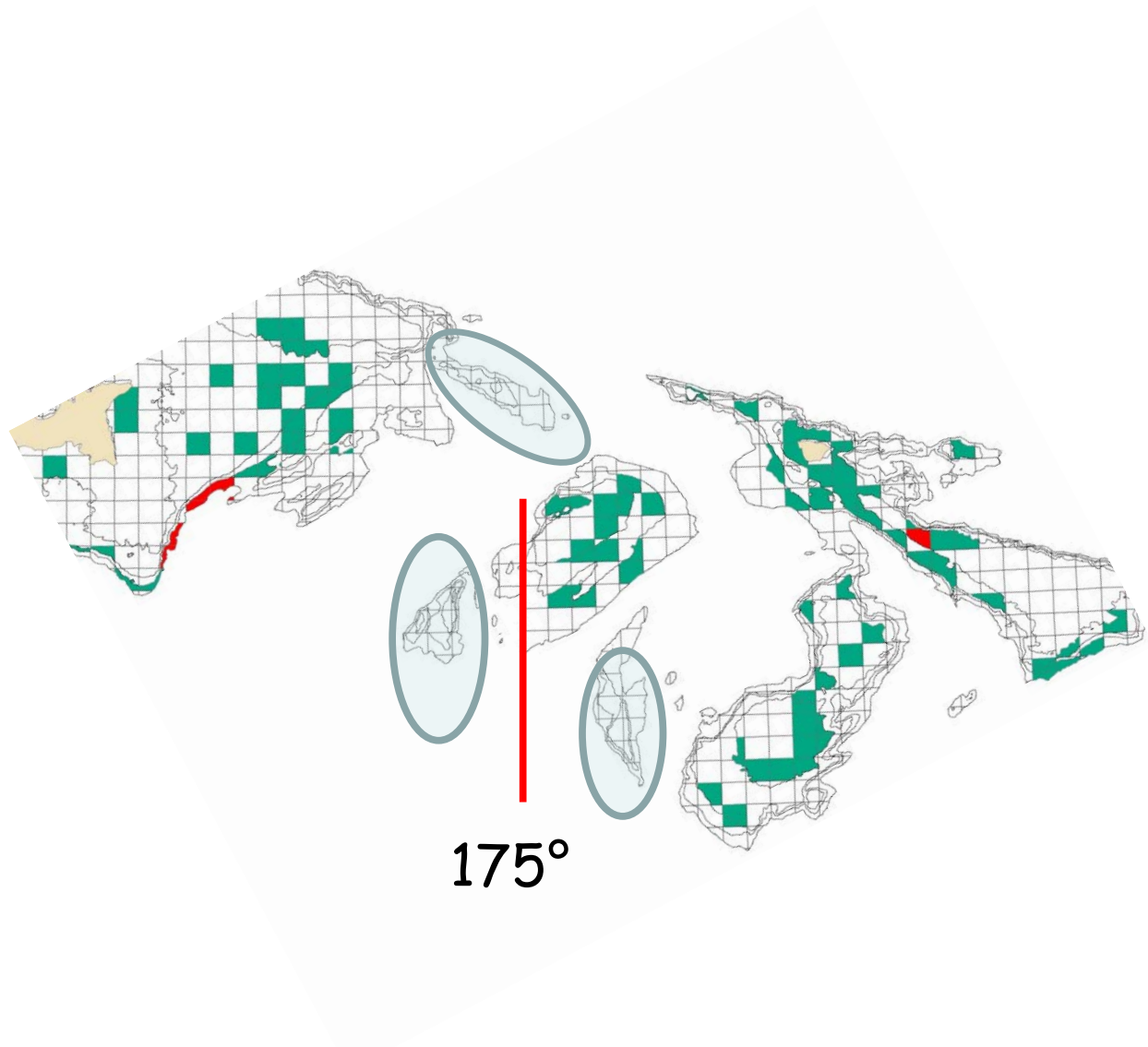


Figure 12. Map of AI trawl survey grid cells in near 175° in the WAI. Sampling locations for future surveys taken from locations successfully sampled in previous surveys (green cells). Red cells are stations classified as untrawlable. The three blue ovals represent fishing grounds that are not sampled by the AI trawl survey.

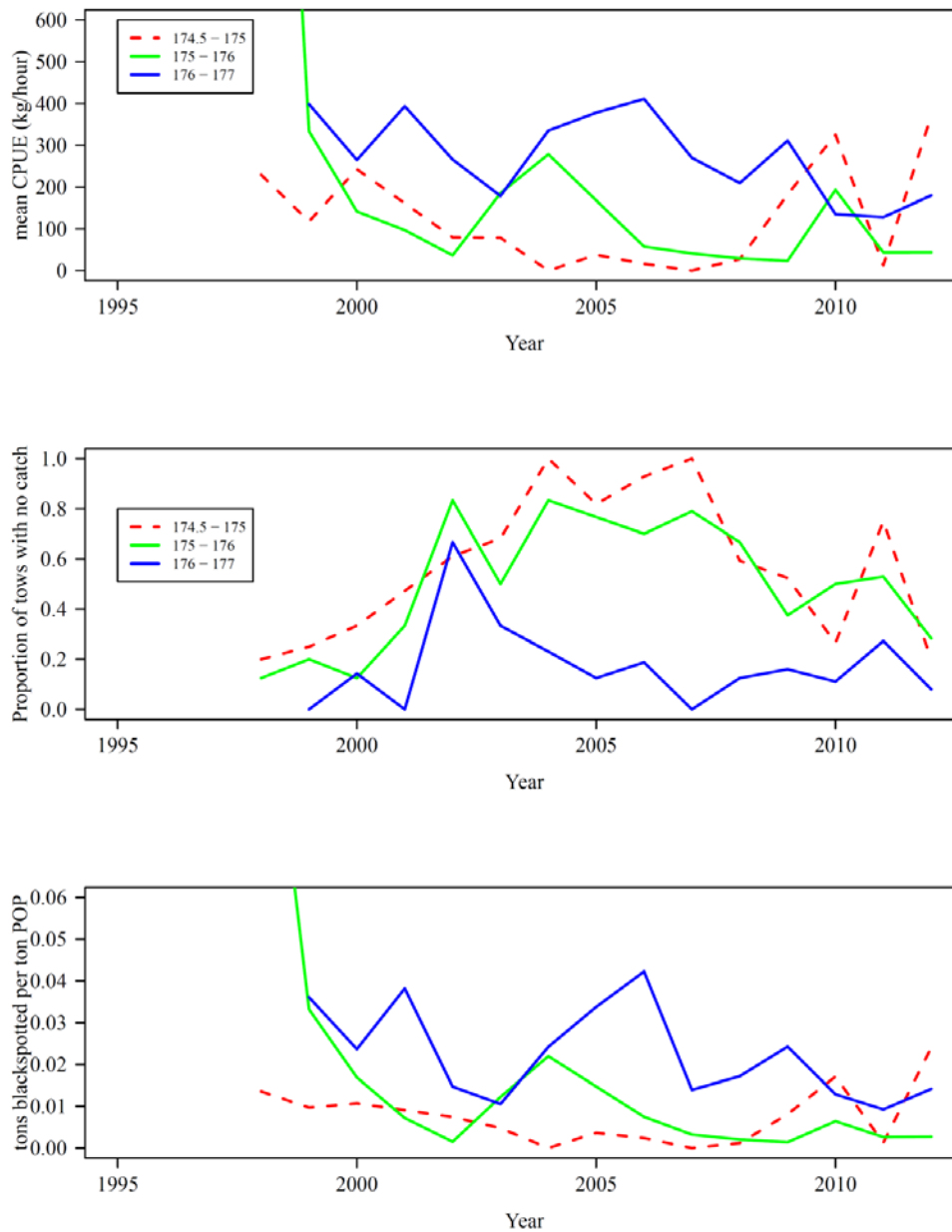


Figure 13. Time series of mean CPUE (top panel; kg/hour), Proportion of tows with no catch (middle panel), and tons of blackspotted/rougeye rockfish catch per ton of POP caught (bottom panel) from filtered fishery tows for three longitude bins in the easternmost portion of the WAI subarea.



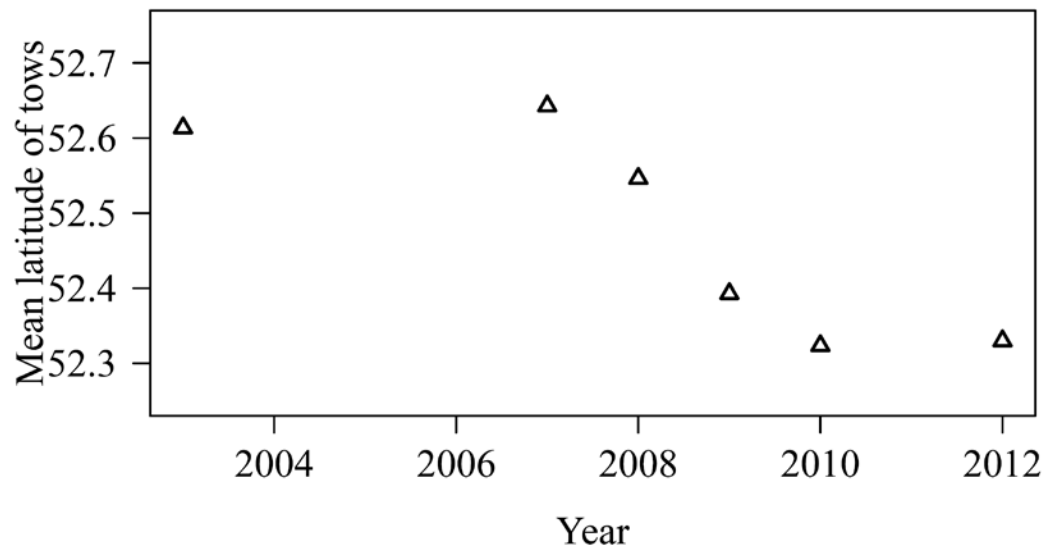


Figure 14. The mean latitude of filtered fishery tows within the 174.5°E-175°E longitude bin in the WAI; only years with 3 or more vessels are shown.

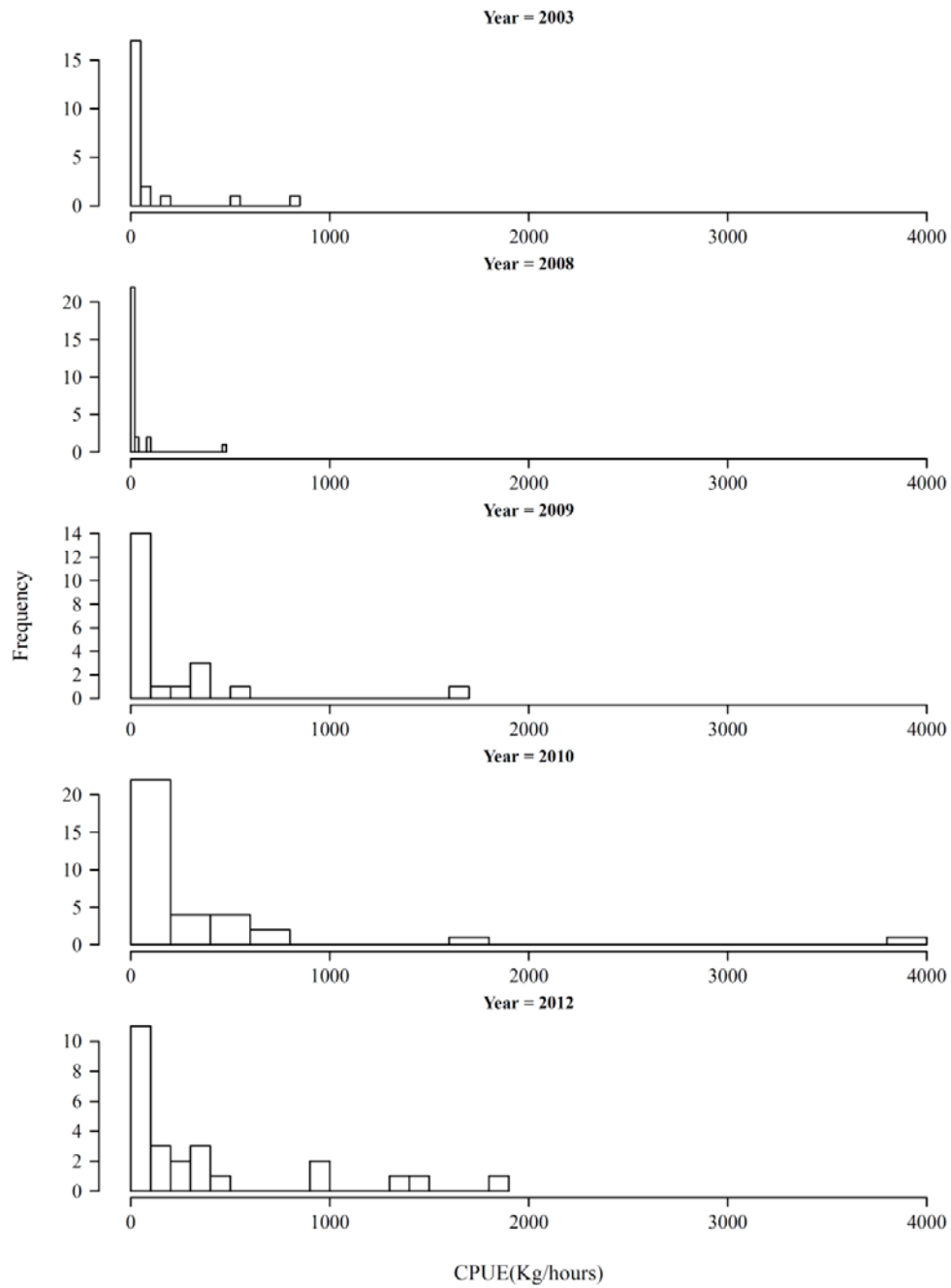


Figure 15. Histogram of CPUE for filtered fishery tows for years with relative low (2003, 2008) and high (2009-2010, 2012) mean CPUE in longitude bin 174.5°E -175°E.

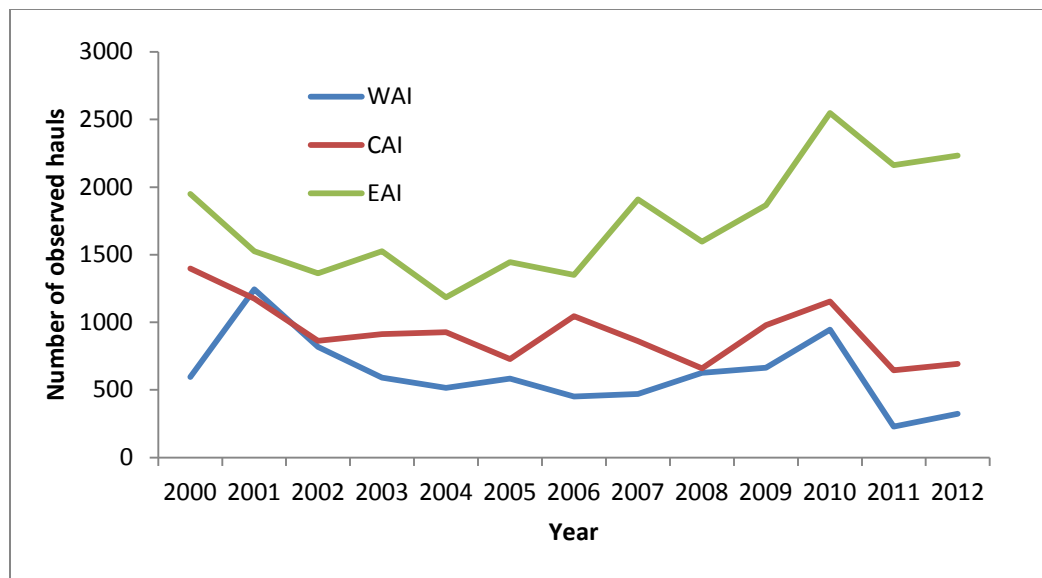


Figure 16. Number of fishery hauls > 100m observed by fishery observers by AI subarea from 2000-2012.

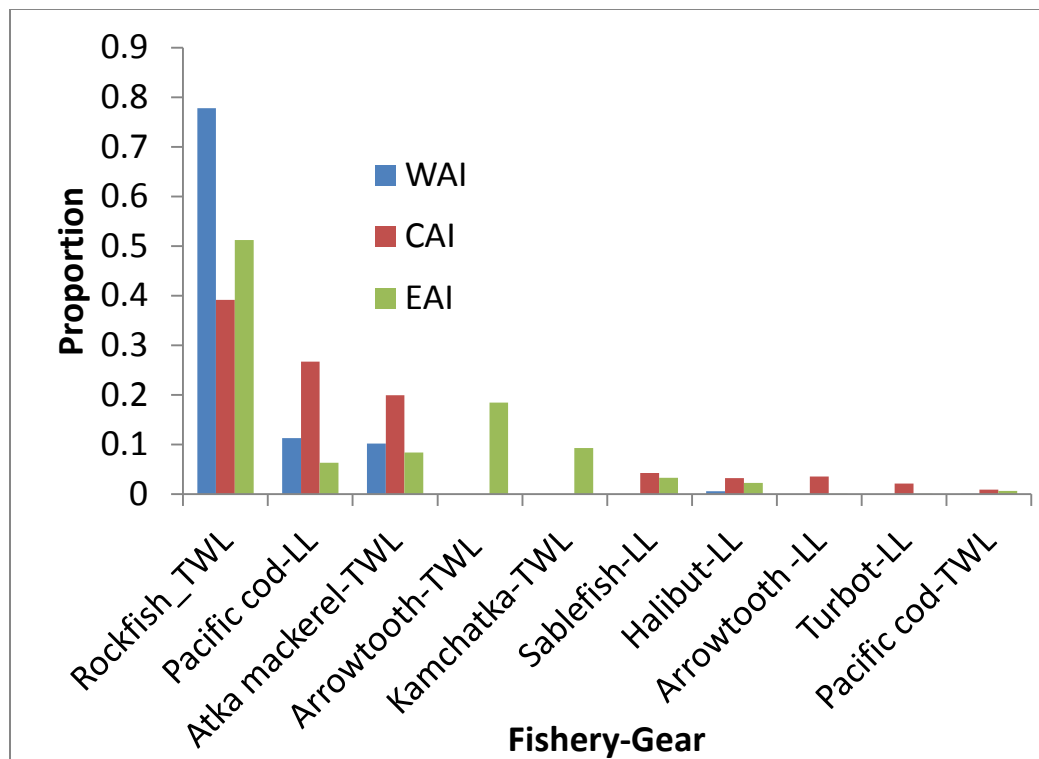


Figure 17. Proportion of Aleutian Islands catch (t) of blackspotted/rougeye rockfish from top gear and target combinations by management area and target fishery in 2004-2012, from the NMFS Alaska Regional Office catch accounting system database.